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Characteristics of the kokanee spawning run in Harvey Creek, Washington and its potential use as an egg source.

Running footer: Kokanee spawning run characteristics

4 tables, 5 figures.

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Abstract

Kokanee populations often require stocking to meet fishery management goals, since natural reproduction may be limited. Many kokanee stocking programs are dependent on eggs collected from a limited number of brood lakes. The anticipated loss of the primary brood source for the statewide kokanee program in Washington State prompted the evaluation of alternative egg sources. I conducted a four-year investigation of the kokanee spawning run in Harvey Creek, a tributary to Sullivan Lake, to evaluate its potential as an egg source. A weir, electrofishing, seining, and carcass surveys were used to collect and enumerate spawning kokanee from 2002 through 2005. Kokanee spawned in Harvey Creek from October through December. Escapement estimates ranged from 4630 in 2002 to 24611 in 2004. There were significant declines in mean total length and weight for both sexes throughout the study period. Fecundity had a significant positive relationship with length ($r^2 = 0.385$, $P < 0.001$). The decreasing trend in mean size was suggestive of density dependence growth. The potential for density dependent effects on growth and fecundity associated with variable abundance may make management of the population for multiple uses difficult, particularly given the lack of information regarding harvest rates, food web interactions, and survival rates of various life stages.

Introduction

Year-to-year variation in abundance is common among kokanee (*Oncorhynchus nerka*) populations (Rieman and Myers 1992, Grover 2006, Buktenica et al. 2007) and when coupled with density dependent effects on growth can result in inconsistent fisheries. Many management agencies in the western United States require stocking of kokanee to meet recreational fishery goals (Wydoski and Bennett 1981, Martinez and Wiltzius 1995, Paragamian and Bowles 1995). The majority of eggs used to support the stocking programs are often collected from a limited number of populations in brood lakes (Martinez and Wiltzius 1995, Parametrix 2003). Most western states have one or two lakes that supply kokanee eggs for their statewide stocking programs. Management of kokanee populations that are important egg sources often requires balancing growth conditions, harvest, predation, and disease risk.

Decreased growth of kokanee related to high densities can result in smaller fish and a lower quality fishery due to reduced catchability and yield (Rieman and Maiolie 1995). Smaller kokanee can be more difficult to catch and less desirable to anglers (Martinez and Wiltzius 1995). Fecundity and body size of kokanee are positively correlated (McGurk 2000), which has implications for populations that are used as egg sources. There are tradeoffs between fish size, fecundity, and abundance that are likely to effect total egg production. Therefore, management decisions about a fishery will affect the population's sustainability and whether it would be able to provide surplus eggs for other water bodies.

More than half of the lakes and reservoirs in Washington State managed for kokanee require stocking to achieve management objectives (Parametrix 2003). The

Washington Department of Fish and Wildlife's (WDFW) statewide kokanee stocking program has a current (2008) goal of approximately 9.8 million fry per year for plants in non-brood source lakes (J. Uehara, WDFW, personal communication). Similar to many other western states, a single population in Lake Whatcom supplies the vast majority of the eggs needed for the kokanee stocking program in Washington. Crawford (1979), Looff (1994), and Parametrix (2003) described the history and operations of the Lake Whatcom kokanee egg collection program, the largest in the United States. Of the 38 lakes and reservoirs in Washington that require some kokanee supplementation to meet management goals, 95% are at least partially dependent on eggs from Lake Whatcom (Parametrix 2003).

An agreement between WDFW, the Lummi Nation, Nooksack Tribe, and the City of Bellingham, Washington has been developed that would restore historic passage of anadromous fish on the Middle Fork Nooksack River above a diversion dam (rkm 11.6), thus eliminating the "regulated viral pathogen free" status of Lake Whatcom kokanee (Parametrix 2003). The loss of the pathogen free status will prevent the use of Lake Whatcom kokanee outside of the Nooksack River drainage. The inability to stock kokanee from Lake Whatcom could potentially lead to a substantial decline in kokanee angling opportunities in Washington State. The WDFW began to evaluate other options for obtaining kokanee eggs in response to the anticipated loss. Among those options was the use of other populations as egg sources within Washington.

The kokanee population in Sullivan Lake is being considered as a potential brood source for stocking several lakes in eastern Washington. Sullivan Lake has a self-sustaining population of kokanee that was first introduced in 1913 (Nine 2005). Kokanee were planted with regularity until the mid-1940s, but it has only received three plants since (1976, 2003, and 2004) (WDFW, unpublished data). Nuclear DNA data indicated that Sullivan Lake and Lake Whatcom kokanee are closely related (WDFW, unpublished data), suggesting the population in Sullivan Lake was established from plants of Lake Whatcom origin kokanee. Prior to 2002, information related to the kokanee fishery and population in Sullivan Lake was sporadic; however, it was known that at least a portion of the population spawned in Harvey Creek, the primary tributary to the lake.

I conducted a four-year investigation of the kokanee spawning run in Harvey Creek to describe its characteristics and evaluate its potential as an egg source. The specific objectives of this project were to 1) describe the run timing, spatial distribution, escapement, size at maturity, fecundity, age at maturity, and egg production of the kokanee spawning population in Harvey Creek, and 2) to discuss its use as a brood source for the kokanee stocking program in eastern Washington.

Study Area

Sullivan Lake is a glacially formed, natural lake located in the Selkirk Range of the Rocky Mountains in the northeast corner of Washington State (48°50'22"N, 117°17'17"W) (Figure 1). A concrete dam was constructed at the outlet of the lake in 1921, which raised the lake elevation approximately 12 m (Bamonte and Bamonte 1996). At its current full pool elevation of 787 m above mean sea level, the lake has a surface area of 567 ha, a maximum depth of 101 m, a mean depth of 58 m, and a volume of 38,495,735 m^3 (Dion et al. 1976). The dam current operations consist of a 6 m drawdown each fall, beginning around 1 October and ending in late January, with refill occurring in the spring with water from snowmelt (P. Buckley, Pend Oreille Public Utility District, personal communication). Most of the property surrounding the lake is Colville National Forest, thus there is little residential development along the lake. The trophic status of Sullivan Lake was classified as oligotrophic (Nine 2005) and aquatic macrophyte densities were low. Sullivan Lake has three tributaries, Hall, Noisy, and Harvey creeks, which drain a total of approximately 13261 ha (Dion et al. 1976). Hall and Noisy creeks are small (1st and 2nd Strahler order), intermittent streams that are not utilized by kokanee.

Harvey Creek (3rd order) is the primary tributary to Sullivan Lake and enters the lake at its southern end. Harvey Creek is approximately 18 km long and has a mean wetted width of 9.8 m in the 1.2 km reach directly upstream of Sullivan Lake at full pool (Olson and Andersen 2004). A 2 km reach of lower Harvey Creek generally has intermittent flow during late summer and fall.

A recent fish survey by Nine (2005) found the fish assemblage of Sullivan Lake, in addition to kokanee, included speckled dace (*Rhinichthys osculus*), redside shiner (*Richardsonius balteatus*), tench (*Tinca tinca*), longnose sucker (*Catostomus catostomus*), westslope cutthroat trout (*O. clarki lewisi*), rainbow trout (*O. mykiss*), brown trout (*Salmo trutta*), mountain whitefish (*Prosopium williamsoni*), pygmy whitefish (*P. coulteri*), burbot (*Lota lota*), and slimy sculpin (*Cottus cognatus*). With the exception of kokanee, salmonids occur in low densities. Sullivan Lake has a long stocking history of rainbow and cutthroat trout; however, regular stocking was discontinued in the early 1990s.

Methods

Fish Weir

I installed a fish weir in Harvey Creek and operated it during the fall kokanee spawning periods (October – December) from 2002 through 2005. The weir was placed directly upstream of the lake-stream interface; however, the length of Harvey Creek available for kokanee spawning progressively increased during the course of the drawdown (October – January). Therefore, I had to move the weir downstream on two occasions each year (late October and early November) to collect kokanee spawning in the newly exposed reach.

The weir consisted of an upstream trap to capture fish migrating upstream, a downstream trap to capture fish migrating downstream, and four to seven panels that were secured in the stream with metal fence posts (Baldwin and McLellan, *in press*). The panels were angled between the traps and the shoreline to funnel fish into the up- or downstream traps. I adjusted the number of panels used in accordance with the width of the stream at each set location. A hardware cloth apron was attached to the lower portion of each panel and it extended approximately 15 cm upstream on the stream bottom. I placed sand bags on the hardware cloth apron, around the traps, and on the shoreline next to the panels to prevent undercutting and side cutting.

I operated the weir between 4 November and 16 December 2002, 15 October and 30 December 2003, 14 October and 30 December 2004, and 11 October and 27 December 2005. The late installation of the weir in 2004 was due to a lack of information regarding run timing. The weir was checked daily until 16 December, with the exception of one to three individual days, after which it was checked approximately three days per week. All of the kokanee captured in the upstream trap were counted, marked with a left pectoral fin clip, examined to determine sex and reproductive condition, and released upstream. Reproductive condition was defined as ripe (gametes flowing easily), mature (gametes not flowing, but not spawned out), and spawned out (all gametes had been expressed). A subsample of kokanee were retained for spawning in 2003 (142 males and 127 females) and 2005 (65 males and 65 females). Total length (TL; mm) and weight were obtained from all fish of each sex captured in the upstream trap during the study in 2002 and 2004 and a subsample of approximately 50% of each sex throughout the study period in 2003 and 2005. The same procedure was conducted for fish captured in the downstream trap, except they were marked with a right ventral fin clip and released downstream of the weir.

An Onset Stowaway Tidbit® temperature logger (-5 to 37, ± 0.2 °C), programmed to record water temperatures every two hours, was attached to the throat of the upstream trap in the thalweg of Harvey Creek. I installed a staff gage in Harvey Creek at the start of weir operation in 2003, 2004, and 2005 to measure stream stage (gage height), which was recorded daily. Discharge (Q) was measured weekly throughout the study period each year according to the methods of Gallagher and Stevenson (1999). Three velocity (m/s) measurements were taken in each cell (20 s measuring period) at 0.6 the depth with a Swoffer® 3000 flow meter and I used the average to calculate the discharge in each cell. I regressed the measured discharge by stream stage each year, and used the resulting equations and daily stream stage measurements to estimate daily discharge.

Electrofishing and Seining

I conducted additional sampling using backpack electrofishing and beach seining in an attempt to account for kokanee that had avoided capture at the weir. Kokanee avoided capture by spawning downstream of the weir, spawning between weir locations, and ascending above the weir during periods of high flow that caused washouts and undercutting. Electrofishing was conducted on one day in both 2002 and 2004 and three days in 2005 with a Smith-Root model 12 battery powered backpack electrofisher with a single loop anode and cable cathode. The time and distance of electrofishing was variable on each occasion; however, it was generally conducted over a 50 m reach and was shorter in duration than 10 min to minimize the disturbance of redds. I seined on one day in both 2002 and 2003 using a seine (1.22 m x 15.24 m; 0.64 cm delta mesh) over an approximately 30 m long reach. Kokanee captured during electrofishing and seining were counted, marked with a left pectoral fin clip, examined to determine sex and reproductive condition, and released upstream of the weir.

Carcass Surveys

I conducted carcass surveys during all study years to enumerate kokanee that avoided capture in the weir or supplemental collection efforts. Kokanee avoided capture when they were in between weir locations on days when the weir was re-located due to lake drawdown, ascended above the weir when there was a failure, or were not captured during electrofishing or seining due to limited effort and poor efficiency. During carcass surveys, I walked both shorelines along the entire length of the kokanee spawning area above and below the weir and netted carcasses, placed them in buckets, and carried them to the lake. I examined each carcass for fin clips, counted, and discarded it in the lake.

In 2004, I tallied the carcasses by sex. I included carcasses removed from the downstream trap in the carcass counts.

Spatial Extent of Spawning

I measured (m) the length of the kokanee spawning reach in Harvey Creek using a string box. The upper and lower extents of spawning were the most upstream and downstream locations where redds were observed during carcass surveys. In order to assess the upper extent, I walked 50 to 100 m upstream of the upper most redd or spawning kokanee during at least one carcass survey per week looking for redds or mature kokanee holding in pools or runs.

Fecundity

I retained a subsample of mature female kokanee for determining fecundity in 2003 (n = 20), 2004 (n = 50), and 2005 (n = 50). Each female sampled was euthanized, measured for TL, weighed, and then I extracted its egg skeins. I placed the skeins from each fish in individual bags filled with stream water and allowed the eggs to water harden for approximately four hours. I then preserved the eggs in 70% ethanol until they were counted.

Age at Maturity

I extracted the otoliths from the carcasses of 50 kokanee (30 females and 20 males) in 2002 to determine the age composition of the spawners. I measured each carcass for standard length (SL; mm), due to decomposed caudal fins, which I converted to TL using the equation TL = 1.202(SL) (Carlander 1969). Otoliths were viewed using a dissecting microscope under low power against a black background with reflected light and the translucent zones (annuli) were counted (Clutter and Whitesel 1956).

Data Analysis

I calculated the total proportion of marked kokanee released upstream of the weir that were recovered during the carcass surveys (*P*) with the equation,

$$P = \frac{\sum R_j}{\sum M_i}$$

where, M_i was the numbered of marked fish released upstream of the weir on day *i* and R_j was the number of marked carcasses recovered during survey *j*. Critical assumptions in the calculation of *P* were that the probabilities of encountering a marked or an unmarked carcass were equal and that all of the marks were recognized. I estimated the number of kokanee that avoided captured (*T*) using the equation (Baldwin and McLellan, *in press*),

$$T = \left(\sum C_j - \sum U_i\right) + (1 - P)\left(\sum C_j - \sum U_i\right)$$

where, C_j was the total number of unmarked carcasses recovered during survey *j* and *U* was the numbered of unmarked kokanee released upstream of the weir on day *i*. Marked carcasses recovered during surveys in 2002 were not recorded, so I used the 2003 proportion (*P*) for the 2002 estimate of *T* because I assumed that recovery rates would have been similar due to similar stream conditions in those years. Total escapement (*E*) was estimated using the equation,

$$E = \sum W_i + \sum F_i + \sum S_i + T$$

where, W_i was the number of unmarked kokanee collected at the weir (both up- and downstream traps) on day *i*, F_i was the number of unmarked kokanee collected during electrofishing on day *i*, S_i was the number of unmarked kokanee collected during seining on day *i*.

I calculated the sex ratios (females:males) by dividing the total number of females by the total number of males captured. Data used for sex ratio calculations were from fish collected in the upstream trap, by electrofishing, and by seining (2002 and 2003); in the upstream trap, by electrofishing, and carcass surveys (2004); and in the up- and downstream traps and by electrofishing (2005).

Mean TL was calculated for kokanee of each sex captured in the upstream trap each year. Mean weight was calculated for mature and ripe kokanee of each sex collected in the upstream trap each year. I included only mature and ripe kokanee in the weight calculations, due to the proportionally large weight loss when gametes were released. I used a Kolmogorov-Smirnov test ($\alpha = 0.15$) to test for normality in the TL, weight, and fecundity distributions. A relatively large alpha was selected for the Kolmogorov-Smirnov test because it increased the probability that I would detect a difference from normality if one existed. I used a Kruskal-Wallis test ($\alpha = 0.05$) to determine differences in TL and weight between years for each sex (Zar 1999). If the null hypothesis was rejected, I used a nonparametric multiple comparisons test with unequal sample sizes (Family Error = 0.20) to determine where the differences occurred. I used a one-way analysis of variance (ANOVA; $\alpha = 0.05$) to test for differences in fecundity between years. If the null hypothesis was rejected, I used the Tukey's test with unequal sample sizes (Family Error = 0.05) to determine where the differences occurred. I used linear regression to determine if a relationship existed between female fork length (FL) and fecundity with data from 2003 through 2005 pooled. I converted female TL to FL for the length-fecundity regression, using the equation FL = 0.915(TL) (Carlander

1969), to allow for comparison with McGurk (2000). The FL and fecundity data was Log_e transformed for the regression analysis.

I estimated egg production each year by multiplying the female escapement by the mean fecundity. Female escapement was calculated by multiplying the proportion of females by the total escapement. I multiplied the upper and lower 95% confidence interval values for fecundity by the female escapement to provide 95% confidence intervals for egg production. Since fecundity data was not collected in 2002, I estimated mean fecundity using the FL-fecundity regression developed with the 2003-2005 data. I used the MINITAB 14 statistical software program (Minitab, Inc. 2005) for all statistical analyses.

Results

Kokanee spawned in Harvey Creek from mid-October to mid-December. The start of the spawning run (first day fish were caught in the weir) occurred on 18, 15, and 14 October in 2003, 2004, and 2005, respectively (Figure 2). The weir was installed after the start of spawning in 2002, so the exact date that mature kokanee first entered Harvey Creek was unknown. The migration was assumed to have started in the middle of October because >100 mature kokanee were observed in Harvey Creek on 23 October 2002 (WDFW, unpublished data). Kokanee were observed in Harvey Creek at the completion of the sampling in mid to late December in all years except 2002; however, fewer than 300 live, presumably spawned out kokanee were observed and catch in the upstream trap had leveled off near zero (Figure 2). Spawning occurred over 468 m in 2002, 2003, and 2005 and the upper extent was limited due to dewatering of the channel in each of those years.

In 2004, discharge was higher so the entire channel remained wetted and spawning activity was observed 297 m further upstream. The total length of the spawning reach in 2004 was 765 m, but greater than 95% of the spawning activity occurred in the same area as other years.

Between 2002 and 2005, mean water temperatures in Harvey Creek during weir operation ranged from 3.6 to 5.7 ^{o}C, with a minimum recorded temperature of 0.9 ^{o}C in 2004 and a maximum of 8.7 ^{o}C in 2003 (Table 1). In 2003, the measured discharge-stream stage relationship was explained by the equation Q = 0.9396(Stage) + 0.1154 (r^2 = 0.973, F = 292.1, df = 9, P <0.001). In 2004, the measured discharge-stream stage relationship was explained by the equation Q = 0.2891(Log_e(Stage)) + 0.7185 (r^2 = 0.955, F = 214.2, df = 11, P <0.001). In 2005, the measured discharge-stream stage relationship was explained by the equation Q = 0.2218(Log_e(Stage)) + 1.0866 (r^2 = 0.981, F = 474.9, df = 10, P <0.001). The mean daily discharge of Harvey Creek during weir operation was 0.20 m^3/s in 2003, 0.88 m^3/s in 2004, and 0.27 m^3/s in 2005 (Table 1). The minimum recorded discharge in Harvey Creek during weir operation was 0.04 m^3/s in 2003 and the maximum was 3.74 m^3/s in 2004.

Most kokanee were collected as carcasses in all years. After subtracting the fish released above the weir without a fin clip ($\sum U_i$), the raw carcass counts for each year ranged from 2140 to 12173 (Table 2). The proportions of marked kokanee recovered in the carcass surveys, P, were 0.613 (2003), 0.124 (2004), and 0.720 (2005). Escapement estimates (E) ranged from 4594 to 24611 (Table 2) and were highly variable with increases >100% each year between 2002 and 2004, followed by a 35% decrease in 2005.

The sex ratio (females:males) ranged from 0.9:1.0 to 1.6:1.0, and was also variable between years (Table 2). The sex ratio with data from all of the years pooled was 1.1:1.0.

The mean TL of female kokanee was 288 mm in 2002 and declined each year to 230 mm in 2005 (Figure 3). The mean TL of males was 289 mm in 2002 and declined each year to 236 mm in 2005 (Figure 3). The decline in TL between each year was significant for both females (H = 2,150, df = 3, P <0.001) and males (H = 1,973, df = 3, P <0.001). The mean weight of mature and ripe females was 200 g in 2002 and declined each year to 98 g in 2005 (Figure 4). The mean weight of mature and ripe males was 218 g in 2002 and declined each year to 107 g in 2005 (Figure 4). The decline in weight between each year was significant for both females (H = 1,410, df = 3, P <0.001) and males (H = 1,557, df = 3, P <0.001).

Fecundity declined significantly each year (ANOVA, F = 69.9, df = 119, P <0.001) (Table 3), and the linear regression indicated there was a strong negative relationship between fecundity and FL of female spawners (ANOVA, F = 73.3, df = 119, P <0.001) (Figure 5). The slope of the length-fecundity regression was within the range (2.04-3.08) reported for 11 other kokanee populations (McGurk 2000); however, the variability in fecundity explained by length (38.5%) was lower than reported (range 41-90%). Estimated egg production increased from approximately 1.27 million in 2002 to 4.45 million in 2004, but declined to 2.59 million in 2005 (Table 4).

There were 50 kokanee aged in 2002 and of those, 34 were age 3 and 16 were age 2. Age 3 females (n = 17) averaged 301 mm TL (SD = 12; range 281-322) and males (n = 17) averaged 316 mm TL (SD = 10; range 289-331). The age 2 females (n = 13) averaged 272 mm TL (SD = 12; range 254-301) and males (n = 3) averaged 291 mm TL (SD=5; range 286-295).

Discussion

The spawn timing and duration in Harvey Creek was within the range (September-December) reported for the Lake Whatcom stock (Crawford 1979, Looff 1994, Parametrix 2003) and other populations established with Lake Whatcom kokanee (Lewis 1971, McLellan et al. 2004, Grover 2006). The late start of the Harvey Creek spawning run was more characteristic of the Lake Whatcom "late-run" referred to in McLellan et al. (2004). A similar "late-run" occurs among Whatcom stock origin populations in Flathead Lake (Fraley et al. 1986) and some Oregon lakes (Lewis 1971). The vast majority of spawning (all in most years) occurred in the reach of Harvey Creek that is inundated by the lake when it is at full pool elevation and the spawning areas are not exposed until the lake is drawn down, beginning on 1 October. Fine sediment accumulates in much of the stream channel within the inundation zone when the lake is at full pool. As the lake elevation declines with the drawdown, the stream re-establishes its channel and some of the fine sediments are scoured out revealing larger substrates. The lake levels and resultant availability of spawning habitat may have selected for the "late-run" component of the Whatcom stock during the 60 years that the population has been self-sustaining.

The majority of the unmarked kokanee were collected during the carcass surveys each year indicating the poor weir capture efficiency. Weir efficiency suffered due to several different factors each year, including weir failure due to high flow events, side cutting, undercutting, and channel migration. Problems were exacerbated by having to relocate the weir during a sampling season due to lake drawdown. Weir counts alone were not sufficient to quantify spawner escapement in Harvey Creek; however, despite poor efficiency, carcass surveys and associated corrections allowed us to generate the escapement estimates.

The initial goal was to enumerate all of the carcasses to arrive at a complete census of spawners; however, this was unrealistic due to losses of fish and carcasses over the course of the spawning season (Baldwin and McLellan, *in press*). Mark-recapture models have been used to estimate spawner escapement for Pacific salmon *Oncorhynchus* spp. (e.g. Schwarz et al. 1993, Arnason et al. 1996, Korman et al. 2002), including the use of carcass recoveries as “recaptures” (Darroch 1961, Miyakoshi and Kudo 1999), but each model has specific assumptions that when violated will bias an estimate (Pollock et al. 1990, Arnason et al. 1996). As discussed in Baldwin and McLellan (*in press*), a mark-recapture model was not used to estimate kokanee escapement because, 1) the intention was to capture the entire escapement at the weir, thus the sampling and marking strategy was not designed to facilitate a mark-recapture estimate (i.e. no strata based marking or recovery, no individual marks), 2) the closure and equal catchability assumptions of a closed pooled Petersen model were violated so the estimates would have had positive bias (Arnason et al. 1996), and 3) the recovery was a complete census (all carcasses remaining in the stream were collected on all surveys) so the proportion of marked kokanee that were removed from the spawning area was known. Because the carcass recovery was a complete census, it was assumed that the estimate was unbiased, and accurate.

The accuracy of the escapement estimates was dependent on the assumptions that the probabilities of collecting a marked or an unmarked carcass were equal and that field staff recognized all of the marks. I believe it was unlikely that predation, scavenging, drift past the weir during high flows, or carcasses being overlooked by field staff was related to whether a fish was marked or unmarked (pectoral fin clipped or not). Nonetheless, if the probability of encountering a marked carcass was greater than for an unmarked one, the corresponding escapement estimate would be biased low. The opposite would occur if the encounter probability of a marked carcass were lower than for an unmarked one. The likelihood that field staff recognized all marks was also high, because the same primary field staff was used in all study years and fin clips were easily recognized, despite fin decomposition. If fin clips were not recognized, the resulting escapement estimate would have been biased high.

The proportion of marked kokanee recovered as carcasses was relatively high in 2003 and 2005 compared to 2004. The low recovery rate in 2004 was likely the result of high flows washing large numbers of carcasses out of the stream when the weir was inoperable. High rates of predation and scavenging could have also contributed to the low recovery rate in 2004. Evidence of predation and scavenging in the form of partially consumed kokanee carcasses along the stream were common in all study years, but the number of these locations appeared to be substantially greater in 2004. Another explanation for the low recovery rate of marked carcasses may have been due to field staff not identifying marks, but this was unlikely as previously discussed. Thus, the combination of higher discharge and increased predation/scavenging likely resulted in the lower recovery of kokanee carcasses in 2004.

The accuracy of our escapement estimate in 2003 (11923) was supported by a 2003 hydroacoustic abundance estimate of 10030 age 3 kokanee in Sullivan Lake (SE = 3520) (Baldwin and McLellan 2005, *in press*). These estimates were similar, but the difference in these estimates could be explained by age 2 spawner escapement. The two estimates may be close enough for management purposes, thus hydroacoustics should be examined further for monitoring kokanee escapement in Harvey Creek (Baldwin and McLellan 2005, *in press*). A hydroacoustics survey is more efficient and cost effective than daily weir operation and carcass surveys. Another advantage of using hydroacoustics to estimate kokanee escapement is the ability to calculate error bounds. Error bounds were unknown with the method used in this study, resulting in the assumption that the escapement estimates were completely accurate which was not likely. By applying the estimated escapement, instead of the escapement error bounds, to the fecundity error bounds, the precision of the egg production estimates was likely overestimated.

The observed variation in kokanee escapement in Harvey Creek was consistent with variable abundance in other populations (Rieman and Myers 1992, Grover 2006, Buktenica et al. 2007). Predation (Beauchamp et al. 1995, Baldwin and Polacek 2002, Baldwin et al. 2003), competition (Spencer et al. 1991), food availability (Martinez and Wiltzius 1995, Buktenica et al. 2007), reservoir operations (Fraley et al. 1986, Martinez and Wiltzius 1995, Paragamian and Bowles 1995), entrainment (Baldwin and Polacek 2002, Maiolie and Stark 2003), and harvest (Rieman and Maiolie 1995) are some of the factors suggested to influence the abundance of kokanee in various locations. Often it is the dynamic interaction of several of these factors, mediated by productivity, that result in variable abundance of kokanee (Martinez and Wiltzius 1995, Buktinica et al. 2007). However, to date no research has been conducted to quantify the factors influencing kokanee abundance in Sullivan Lake. Kokanee in Sullivan Lake support a recreational fishery and are the primary prey source for burbot (Nine 2005). They are also subject to reservoir management that likely affects the availability and quality of spawning habitat, lake productivity, food availability, and entrainment. Understanding how these factors interact to influence kokanee abundance should be considered if this population is to be managed to provide a fishery, forage for burbot, and most importantly a reliable egg source.

O. nerka may have natural cycles in abundance. In the absence of human manipulations, kokanee abundance in Crater Lake, Oregon fluctuated over a 10-year period and was hypothesized to have oscillating periodicity (Buktenica et al. 2007). Several Fraser River sockeye stocks exhibit cyclical fluctuations in abundance with a periodicity of four years (Goodlad et al. 1974, Ricker 1997, Myers et al. 1998). These stocks, however, are subjected to harvest management. Harvest or other sources of substantial mortality may influence the amplitude or periodicity of *O. nerka* abundance cycles (Myers et al. 1998). No consistent pattern in Sullivan Lake kokanee escapement (abundance) with regular amplitude or periodicity was identified, possibly due to the relatively short duration of the study.

Significant declines in TL and weight of kokanee spawning in Harvey Creek was suggestive of density dependent growth. Negative effects of abundance on growth have been demonstrated for many species of Pacific salmon, including both anadromous sockeye salmon (Kyle et al. 1988, Bigler et al. 1996, Bugaev et al. 2001) and nonanadromous kokanee (Rieman and Myers 1992, Martinez and Wiltzius 1995, Grover 2006). When pre-smolt sockeye salmon and kokanee occur in high densities, they can reduce the abundance of large (>1.2 mm) *Daphnia*, their preferred prey, through selective predation and shift the zooplankton species composition to smaller, less desirable species (Goodlad et al. 1974, Martinez and Wiltzius 1995, Mazumder and Edmundson 2002). The available zooplankton data was suggestive of substantial selective predation on large *Daphnia* by kokanee, the primary planktivore in Sullivan Lake. In 2003, the mean length of *Daphnia* (0.78 mm; range 0.4 to 1.4) in Sullivan Lake was small relative to the sizes selected for by kokanee (Nine 2005). In addition, the zooplankton composition in Sullivan Lake was dominated by small-bodied copepods (70%), followed by *Daphnia* (23%), *Bosmina* (6%), and rotifers (1%). Schneidervin and Hubert (1987) found that the occurrence of large *Daphnia* in the diet of kokanee (94.4%) was substantially higher than in Flaming Gorge Reservoir, Wyoming-Utah (14.0%). Zooplankton species composition in Flaming Gorge was primarily comprised of small copepods and rotifers. *Daphnia pulex* were not detected in zooplankton samples and mean size of *Daphnia galeata mendotae* was small (≤ 0.87 mm) in years when kokanee abundance was high in Lake Granby, Colorado (Martinez and Wiltzius 1995). When kokanee abundance was low, *Daphnia pulex* were detected and mean size of *Daphnia* spp. (*D. galeata mendotae* and *D. pulex*) was large (≥ 1.20 mm). Nonetheless, drawing conclusions about density-dependent effects on kokanee growth in Sullivan Lake using the existing zooplankton data is presumptuous given that it comprises one year of data.

The decline in both body size and escapement in 2005 suggested that density dependent effects were occurring across multiple age classes. In a simple density dependent growth model, body size and abundance have an inverse relationship. Assuming escapement is indicative of abundance, when the body size of spawning kokanee declined an increase in escapement was expected (Grover 2006). Failure of this model can occur when escapement is not representative of in-lake abundance and associated growth conditions. Escapement and growth could both decline in cases where intraspecific competition occurs across multiple age classes but spawners comprise a single age class. Intraspecific competition within and between year classes can affect kokanee growth (Ward and Larkin 1964). Between year class interactions have been found to be segregated between young age classes (age 0 and age 1) and old age classes (age 2 and age 3) (Fraley et al. 1986). Kokanee age at maturity can shift from age 2 to age 3 as growth conditions decline (Grover 2005). The spawning run in Harvey Creek was comprised of 68% age 3 fish in 2002 when the escapement was lowest and mean size was greatest. As the size of mature kokanee declined over the subsequent study years, it is reasonable to assume that more fish matured at age 3. Assuming age 2 and age 3 kokanee competed with each other in Sullivan Lake and the spawning run was primarily age 3 fish, 2005 spawners could have experienced slow growth despite having lower abundance, particularly if the abundance of age 2 kokanee was high relative to age 3 kokanee. The stocking of approximately 40000 kokanee fry (brood year 2002) in 2003 may have artificially increased the abundance of the age 2 fish in 2005 (2006 spawners), resulting in artificially high intraspecific competition.

A decline in escapement without a complementary increase in growth, because of density dependent effects, could result in lower egg production relative to the escapement. Declining fecundity, associated with smaller fish, and lower escapement results in substantially lower egg production. Estimated total egg production in Harvey Creek in 2005 was 9-12% lower than in 2003, despite an escapement that was roughly 35% higher.

Rieman and Myers (1992) found there was little or no density dependent effect on the growth of kokanee up to age 1, suggesting population self-regulation occurs at older age classes. Their proposed mechanism for population self-regulation was increased densities result in smaller female spawners, lower fecundity, and smaller eggs. A decrease in fecundity and decreased egg survival, as a consequence of smaller eggs, would result in fewer age 0 recruits to the lake. However, reductions in egg size in relation to fish size do not appear to occur with kokanee, suggesting that the egg size component of the population regulation hypothesis may not exist (Kaeriyama et al. 1995, McGurk 2000).

In some populations, reductions in egg survival associated with increased abundance may be the result of redd superimposition. Redd superimposition has been suggested to result in substantial egg mortality in salmonids (McNeil 1964, Fukushima et al. 1998, Morbey and Ydenberg 2003). When escapement is high relative to available spawning habitat, kokanee will crowd into the available habitat, form large aggregations, and lose aggressive territorial behaviors (Grover 2006). Late arriving kokanee may induce high mortality of eggs in existing redds through physical shock from gravel agitation during construction of their redds on top of existing redds. Salmonid eggs are sensitive to physical shock through the epiboly stage of development, or about 12 days post fertilization depending on water temperature (Jensen and Alderdice 1989). When evaluating a sampling technique for pink salmon eggs that required agitating the eggs and gravel with water discharged beneath the gravel, Collins et al. (2000) found that the eggs were susceptible to trauma until the eye pigmentation stage (day 20 at 8-10 ^{o}C). Water temperatures in Harvey Creek during the kokanee spawning period (0.9-8.7 ^{o}C) were typically colder than in the Collins et al. (2000) study. Thus, the length of time that kokanee eggs in redds in Harvey Creek would be susceptible to physical trauma from superimposition would be greater than 20 days. An extended period of susceptibility (i.e. >20 days) to physical trauma experienced by kokanee eggs in Harvey Creek may result in an increased probability of mortality due to physical trauma. Dislodged eggs may also be distributed to areas without adequate dissolved oxygen, flow, sediment composition, or temperature. Therefore, in streams with limited spawning habitat, large escapement may lead to decreased egg survival through redd superimposition.

Spawning habitat in Harvey Creek appeared to be limited in relation to the escapement in all of the study years. There was an estimated 802 m^2 of kokanee spawning habitat in Harvey Creek, which could support approximately 864 redds without superimposition, based on a mean area for a kokanee redd of approximately 0.93 m^2 (Parametrix 2003). Female escapement exceeded 2384 and assuming most females attempted at least one redd (0.93 m^2), superimposition occurred in all study years. Individual redds were rarely observed, which indicated superimposition; however, the amount and affect on egg survival likely varied with differences in escapement. Dead eggs (white) were observed during the spawning period in all years and there appeared to be substantially more dead eggs in 2004 when escapement was highest. Redd superimposition likely occurred in Harvey Creek, since escapement exceeded available habitat, and thus likely resulted in surplus egg production; however, the level of superimposition that results in decreased recruitment of kokanee in Sullivan Lake was not quantified.

The variability in kokanee abundance and body size, as well as lake productivity, should be considered in the management of the Sullivan Lake fishery. A lake with high densities of small fish has the potential to yield fewer fish to the fishery due to reduced catchability of the smaller fish (Rieman and Maiolie 1995). Predictive models indicated that the relative catchability of adult kokanee increased with body size, regardless of lake productivity, and relative yield decreased at densities <50 fish/ha in lakes with intermediate (Secchi disk depth = 6 m) or low (Secchi disk depth = 8 m) productivity. In low productivity lakes, relative catchability and yield approached zero at densities near 75 fish/ha. In 2003, the estimated density of age 2 and age 3 kokanee in Sullivan Lake was 58 fish/ha (Baldwin and McLellan 2005). Assuming the escapement estimates are indicative of abundance, the density of age 2 and 3 kokanee has likely exceeded 58 fish/ha since 2003. While not evaluated, the high densities of kokanee in Sullivan Lake, a low productivity lake (mean Secchi disk depth =10.4 m) (Nine 2005), likely provided a poor fishery between 2003 and 2005. The effects of kokanee density on growth (Rieman and Myers 1992), catchability, and yield (Rieman and Maiolie 1995) were more pronounced in waters with low productivity. Thus, a relatively small reduction in Sullivan Lake kokanee density should result in relatively large increases in kokanee size, catchability, and yield; however, managers must be careful not implement actions that may reduce the density so much that the population becomes at risk of collapse. Implementing management actions to reduce densities intended to improve the quality of the fishery may also come at the expense of egg production.

The results of this study, particularly the high female escapement relative to the available spawning habitat, indicate there is surplus egg production by the kokanee spawning in Harvey Creek at least in some years. The potential for surplus eggs make the Sullivan Lake kokanee population a good candidate for use as a brood source to replace a portion of the lost production from Lake Whatcom. High variability in escapement may be indicative of variable abundance. The potential for density dependent effects on growth and fecundity associated with variable abundance may make management of the population for multiple uses difficult, particularly given the lack of information regarding harvest rates, food web interactions, and survival rates of various life stages. The low productivity of Sullivan Lake only increases the difficulty due to the relatively small margin for error. Studies to determine the factors that influence kokanee abundance in Sullivan Lake should be considered before substantial egg collection activities are instituted. The fluctuations in abundance may potentially be dampened by developing escapement and egg deposition targets for Harvey Creek that maximize egg to fry survival and by extracting the excess production for use in the statewide kokanee program. Nonetheless, variability in escapement and egg production should be expected. A range of escapement targets could be developed with knowledge of the variability in abundance, escapement, and resultant egg production under a range of food availability (productivity) and the ensuing density dependent growth by age class. The target escapement and egg deposition values should balance the desire to provide a fishery and collect eggs.

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Literature Cited

Arnason, A. N., C. W. Kirby, C. J. Schwarz, and J. R. Irvine. 1996. Computer analysis of data from stratified mark-recovery experiments for estimation of salmon escapements and other populations. Canadian Technical Report of Fisheries and Aquatic Sciences 2106.

Baldwin, C., and M. Polacek. 2002. Evaluation of limiting factors for stocked kokanee and rainbow trout in Lake Roosevelt, WA. Report FPA 04-03. Washington Department of Fish and Wildlife, Olympia.

Baldwin, C. M., J. G. McLellan, M. C. Polacek, and K. Underwood. 2003. Walleye predation on hatchery releases of kokanees and rainbow trout in Lake Roosevelt, Washington. North American Journal of Fisheries Management 23:660-676.

Baldwin, C. M., and J. G. McLellan. 2005. Fisheries survey of the limnetic zone of Sullivan Lake, Washington, using hydroacoustics and gill nets, September 2003. Report FPT 05-01. Washington Department of Fish and Wildlife, Olympia.

Baldwin, C. M., and J. G. McLellan. *In press*. Use of gill nets as target verification of a hydroacoustic fisheries survey of kokanee in Sullivan Lake, Washington. North American Journal of Fisheries Management.

Bamonte, T., and S. S. Bamonte. 1996. History of Pend Oreille County. Tornado Creek Publications, Spokane, WA.

Beauchamp, D. A., M. G. LaRiviere, and G. L. Thomas. 1995. Evaluation of competition and predation as limits to juvenile kokanee and sockeye salmon production in Lake Ozette, Washington. North American Journal of Fisheries Management 15:193-207.

Bigler, B. S., D. W. Welch, and J. H. Helle. 1996. A review of size trends among North Pacific salmon (*Oncorhynchus* spp.). Canadian Journal of Fisheries and Aquatic Sciences 53:455-465.

Bugaev, V. F., D. W. Welch, M. M. Selifonov, L. E. Grachev, and J. P. Eveson. 2001. Influence of marine abumndance of pink (Oncorhynchus gorbuscha) and sockeye salmon (O. nerka) on growth of Ozernaya River sockeye. Fisheries Oceanography 10:26-32.

Buktenica, M. W., S. F. Girdner, G. L. Larson, and C. D. McIntire. 2007. Variability of kokanee and rainbow trout food habits, distribution, and population dynamics, in an oligotrophic lake with no manipulative management. Hydrobiologia 574:235-264.

Carlander, K. D. 1969. Handbook of freshwater fishery biology, volume one. The Iowa State University Press, Ames, IA.

Clutter, R. I., and L. E. Whitesel. 1956. Collection and interpretation of sockeye salmon scales. International Pacific Salmon Fisheries Commission Bulletin IX.

Collins, K. M., E. L. Brannon, L. L. Moulton, M. A. Cronin, and K. R. Parker. 2000. Hydraulic sampling protocol to estimate natural embryo mortality of pink salmon. Transactions of the American Fisheries Society 129:827-834.

Crawford, B. A. 1979. The origin and history of the trout brood stocks of the Washington Department of Game. Fishery Research Report. Washington State Game Department, Olympia. Unpublished report on file at Washington Department of Fish and Wildlife, Olympia.

Darroch, J. N. 1961. The two-sample capture-recapture census when tagging and sampling are stratified. Biometrika 48:241-260.

Dion, N. P., G. C. Bortelson, J. B. McConnell, and L. M. Nelson. 1976. Reconnaissance data on lakes in Washington: Pend Oreille, Spokane, and Stevens counties. Water Supply Bulletin 43, Volume 7. Washington Department of Ecology, Olympia, WA.

Fraley, J. J., S. L. McMullin, and P. J. Graham. 1986. Effects of hydroelectric operations on the kokanee population in the Flathead River system, Montana. North American Journal of Fisheries Management 6:560-568.

Fukushima, M., T. J. Quinn, and W. W. Smoker. 1998. Estimation of eggs lost from superimposed pink salmon (*Oncorhynchus gorbuscha*) redds. Canadian Journal of Fisheries and Aquatic Sciences 55:618-625.

Gallagher, A. S., and N. J. Stevenson. 1999. Streamflow. I*n* M.B. Bain and N.J. Stevenson (editors), Aquatic habitat assessment: common methods, American Fisheries Society, Bethesda, MD. Pp. 149-158.

Goodlad, J. C., T. W. Gjernes, and E. L. Brannon. 1974. Factors affecting sockeye salmon (*Oncorhynchus nerka*) growth in four lakes of the Fraser River system. Journal of the Fisheries Research Board of Canada 31:871-892.

Grover, M. C. 2005. Changes in size and age at maturity in a population of kokanee *Oncorhynchus nerka* during a period of declining growth conditions. Journal of Fish Biology 66:122-134.

Grover, M. C. 2006. Evaluation of a negative relationship between abundance during spawning and size at maturity in kokanee. Transactions of the American Fisheries Society 135:970-978.

Jensen, J. O. T., and D. F. Alderdice. 1989. Comparison of mechanical shock sensitivity of eggs of five Pacific salmon (*Oncorhynchus*) species and steelhead trout (*Salmo gairdneri*). Aquaculture 78:163-181.

Kaeriyama, M., S. Urawa, and M. Fukuwaka. 1995. Variation in body size, fecundity, and egg size of sockeye and kokanee salmon, *Oncorhynchus nerka*, released from hatchery. Scientific Report Hokkaido Salmon Hatchery 49:1-9.

Korman, J., R. N. M. Ahrens, P. S. Higgins, and C. J. Walters. 2002. Effects of observer efficiency, arrival timing, and survey life on estimates of escapement for steelhead trout (*Oncorhynchus mykiss*) derived from repeat mark-recapture experiments. Canadian Journal of Fisheries and Aquatic Sciences 59:1116-1131.

Kyle, G. B., J. P. Koenings, and B. M. Barrett. 1988. Density-dependent, trophic level responses to an introduced run of sockeye salmon (*Oncorhynchus nerka*) at Frazer Lake, Kodiak Island, Alaska. Canadian Journal of Fisheries and Aquatic Sciences 45:856-867.

Lewis, S. L. 1971. An evaluation of three kokanee races in Oregon lakes. Federal Aid Completion Report. F-71-R-6, Job 8. Oregon State Game Commission.

Loof, A. C. 1994. Lake Whatcom kokanee management history and evaluation of recent population declines. M.S. Thesis. University of Washington, Seattle.

Maiolie, M., and E. Stark. 2003. Dworshak reservoir kokanee population monitoring. 2001 Annual Report, Project Number 198709900, BPA Document No. DOE/BP-00004381-2. Bonneville Power Administration, Portland, OR.

Martinez, P. J., and W. J. Wiltzius. 1995. Some factors affecting a hatchery-sustained kokanee population in a fluctuating Colorado reservoir. North American Journal of Fisheries Management 15:220-228.

Mazumder, A., and J. A. Edmundson. 2002. Impact of fertilization and stocking on trophic interactions and growth of juvenile sockeye salmon (*Oncorhynchus nerka*). Canadian Journal of Fisheries and Aquatic Sciences 59:1361-1373.

McGurk, M. D. 2000. Comparison of fecundity-length-latitude relationships between nonandramous (kokanee) and anadromous sockeye salmon (*Oncorhynchus nerka*). Canadian Journal of Zoology 78:1791-1805.

McLellan, H. J., J. G. McLellan, A. T. Scholz. 2004. Evaluation of release strategies for hatchery kokanee in Lake Roosevelt, Washington. Northwest Science 78:158-167.

McNeil, W. J. 1964. Redd superimposition and egg capacity of pink salmon spawning beds. Journal of the Fisheries Research Board of Canada 21:1385-1396.

Miyakoshi, Y., and S. Kudo. 1999. Mark-recapture estimation of escapement of Masu salmon *Oncorhynchus masou* with a comparison to a fence count. North American Journal of Fisheries Management 19:1108-1111.

Morbey, Y. E., and R. C. Ydenberg. 2003. Timing games in the reproductive phenology of female Pacific salmon (*Oncorhynchus* spp.). The American Naturalist 161:284-298.

Myers, R. A., G. Mertz, J. M. Bridson, and M. J. Bradford. 1998. Simple dynamics underlie sockeye salmon (*Oncorhynchus nerka*) cycles. Canadian Journal of Fisheries and Aquatic Sciences 55:2355-2364.

Nine, B. D. 2005. Fishery and limnological survey of Sullivan Lake, Pend Oreille County, WA. M.S. Thesis. Eastern Washington University, Cheney.

Olson, J., and T. Andersen. 2004. Kalispel resident fish project, 2003-2004 annual report. Project No. 199500100, BPA Document No. DOE/BP 00004574-2. Bonneville Power Administration, Portland, OR.

Paragamian, V. L., and E. C. Bowles. 1995. Factors effecting survival of kokanees stocked in Lake Pend Oreille, Idaho. North American Journal of Fisheries Management 15:208-219.

Parametrix. 2003. Lake Whatcom and Bellingham hatcheries production replacement feasibility report. Final report. Unpublished report on file at Washington Department of Fish and Wildlife, Olympia.

Pollock, K. H., J. D. Nichols, C. Brownie, and J. E. Hines. 1990. Statistical inference for capture-recapture experiments. Wildlife Monograph 107. The Wildlife Society, Bethesda, MD.

Ricker, W. E. 1997. Cycles of abundance among Fraser River sockeye salmon (*Oncorhynchus nerka*). Canadian Journal of Fisheries and Aquatic Sciences 54:950-968.

Rieman, B. E., and D. L. Myers. 1992. Influence of fish density and relative productivity on growth of kokanee in ten oligotrophic lakes and reservoirs in Idaho. Transactions of the American Fisheries Society 121:178-191.

Rieman, B. E., and M. A. Maiolie. 1995. Kokanee population density and resulting fisheries. North American Journal of Fisheries Management 15:229-237.

Schneidervin, R. W., and W. A. Hubert. 1987. Diet overlap among zooplanktophagous fishes in Flaming Gorge Reservoir, Wyoming-Utah. North American Journal of Fisheries Management 7:379-385.

Schwarz, C. J., R. E. Bailey, J. R. Irvine, and F. C. Dalziel. 1993. Estimating salmon spawning escapements using capture-recapture methods. Canadian Journal of Fisheries and Aquatic Sciences 50:1181-1197.

Spencer, C. N., B. R. McClelland, and J. A. Stanford. 1991. Shrimp stocking, salmon collapse, and eagle displacement. BioScience 41:14-21.

Ward, F., and P. Larkin. 1964. Cyclic dominance in Adams River sockeye salmon. International Pacific Salmon Commission Progress Report 11.

Wydoski, R. S., and D. H. Bennett. 1981. Forage species in lakes and reservoirs of the western United States. Transactions of the American Fisheries Society 110:764-771.

Zar, J.H. 1999. Biostatistical analysis, fourth edition. Prentice Hall, NJ.

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TABLE 1. Harvey Creek water temperature and discharge during kokanee weir operation from 2002 through 2005. Standard deviations are shown in parentheses.

	Temperature (°C)			Discharge (m^3/s)		
Year	n	Mean	Range	n	Mean	Range
2002	1002	5.7 (0.9)	1.6-6.9			
2003	1821	5.7 (0.7)	2.9-8.7	62	0.20 (0.08)	0.04-0.45
2004	1837	3.6 (1.4)	0.9-7.9	67	0.88 (0.45)	0.41-3.74
2005	1813	5.6 (1.2)	1.0-8.1	74	0.27 (0.13)	0.15-0.81

TABLE 2. Raw counts of unmarked kokanee of each sex, carcass count totals, estimated number that avoided capture in the weir or by electrofishing or seining (T), proportion of marked kokanee recovered as carcasses (P), estimated escapement (E), and sex ratios (female:male) in Harvey Creek during the spawning runs from 2002 through 2005.

Collection Method	Females	Males	Unknown	Total	P	Sex ratio
2002						
Weir - upstream trap[1] (W_i)	643	371	28	1042		
Weir - downstream trap[1] (W_i)	24	50	2	76		
Electrofishing[1] ($\sum F_i$)	59	43	-	102		
Seining[1] ($\sum S_i$)	270	142	-	412		
Carcass counts ($\sum C_j$-$\sum U_i$)	-	-	2414	2140[2]		
Number avoided capture (T)				858	0.613	
Escapement (E)				4594		1.6:1.0
2003						
Weir - upstream trap[1] (W_i)	913	1025	-	1938		
Weir - downstream trap[1] (W_i)	133	179	15	312		
Seining[1] ($\sum S_i$)	191	255	-	446		
Carcass counts ($\sum C_j$-$\sum U_i$)	-	-	6634	6564[3]		
Number avoided capture (T)				2663	0.613	
Escapement (E)				11923		0.9:1.0
2004						
Weir - upstream trap[1] (W_i)	886	633	28	1547		
Weir - downstream trap[1] (W_i)	6	7	1	17		

Electrofishing (20 Oct.)[1] ($\sum F_i$)	29	104	-	133		
Electrofishing (22 Nov.) ($\sum F_i$)	65	-	-	65		
Carcass counts ($\sum C_j$-$\sum U_i$)	6553	5634	-	12173[4]		
Number avoided capture (T)				10679	0.124	
Escapement (E)				24611		1.2:1.0
2005						
Weir - upstream trap[1] (W_i)	1563	1981	-	3544		
Weir - downstream trap[1] (W_i)	24	19	-	43		
Electrofishing[1] ($\sum F_i$)	1845	1942	-	3787		
Carcass counts ($\sum C_j$-$\sum U_i$)	-	-	7891	6763[5]		
Number avoided capture (T)				1904	0.720	
Escapement (E)				16041		0.9:1.0

[1]Counts used to calculate sex ratio.

[2]$\sum U_i$ = 274.

[3]$\sum U_i$ = 70.

[4]$\sum U_i$ = 31.

[5]$\sum U_i$ = 1128.

TABLE 3. Mean (SD) of total length, weight, and fecundity of female kokanee spawning in Harvey Creek in 2003 through 2005 subsampled for fecundity counts. Mean fecundity was significantly different between years (ANOVA, *P* <0.001; Tukey test Family Error = 0.05).

Year	n	Total Length (mm)	Weight (g)	Fecundity (no. eggs)
2003	20	262 (12)	120 (20)[1]	471 (58)
2004	50	243 (6)	124 (8)[2]	351 (55)
2005	50	228 (8)	97 (9)	314 (42)

[1]n = 19

[2]n = 49

TABLE 4. Estimated female escapement, fecundity, and egg production (95% confidence interval) by kokanee in Harvey Creek from 2002 through 2005.

Year	Female Escapement	Fecundity	Egg Production (millions)
2002	2384	532[1]	1.27
2003	6138	471 (446-497)	2.89 (2.74-3.05)
2004	12669	351 (336-366)	4.45 (4.25-4.64)
2005	8258	314 (302-326)	2.59 (2.50-2.69)

[1]Estimated using the FL-fecundity relationship developed with 2003-2005 data.

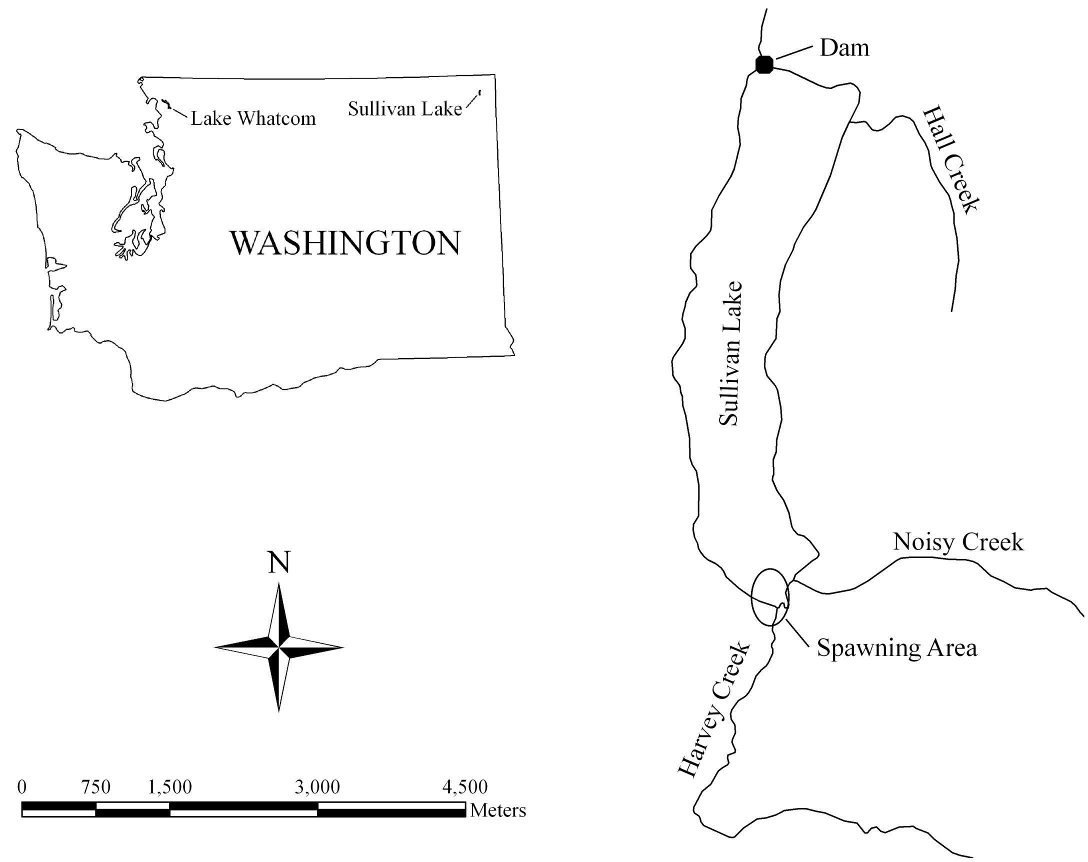

Figure 1. Sullivan Lake and the Harvey Creek study area. The inset indicates the locations of Sullivan Lake and Lake Whatcom (original source stock of kokanee). Lake Whatcom is in the Nooksack River drainage. Scale bar applies to the Harvey Creek study area map.

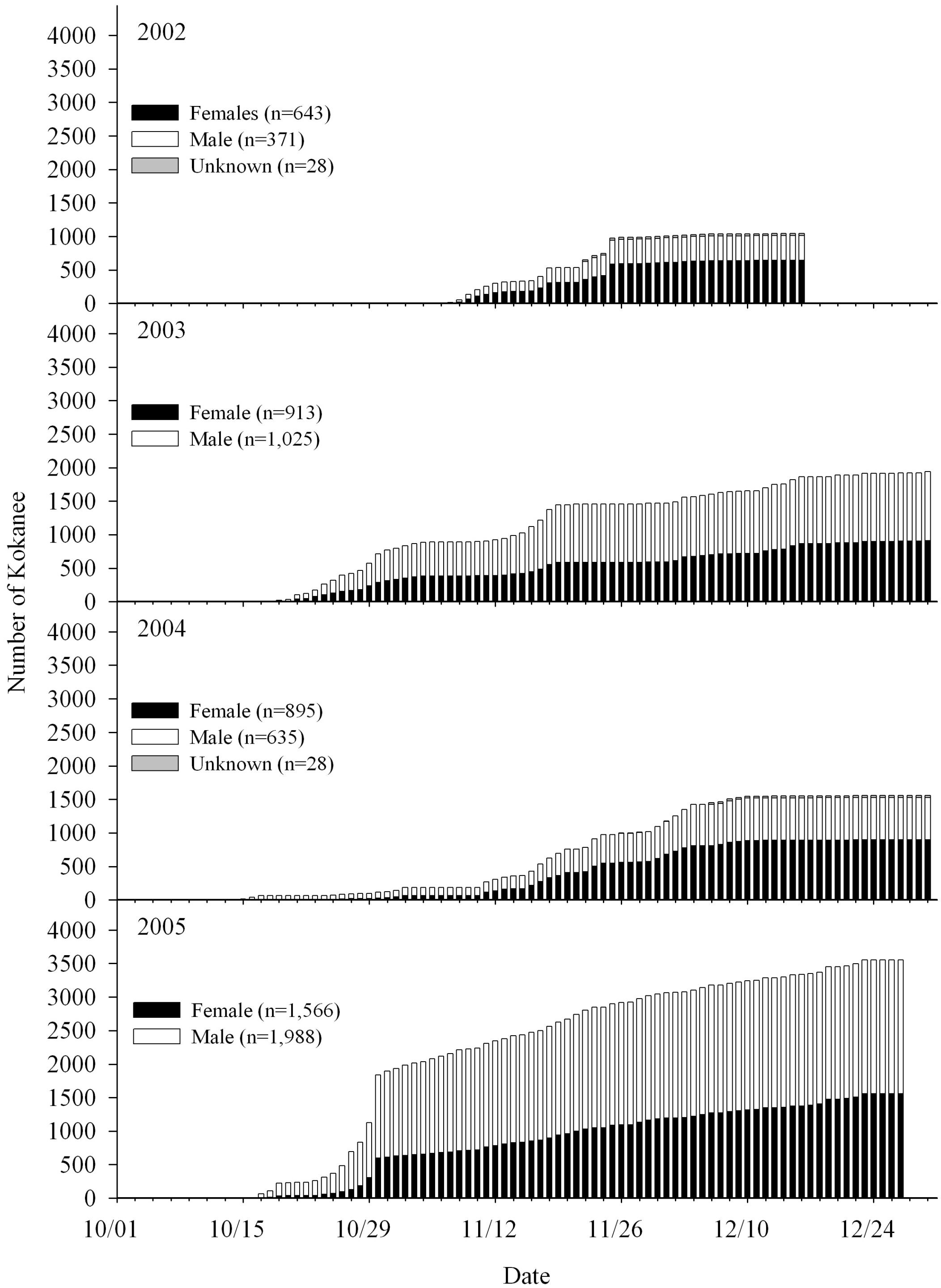

Figure 2. Cumulative catch of kokanee collected in the upstream trap portion of the weir operated in Harvey Creek during the kokanee spawning period (October – December) in 2002 through 2005.

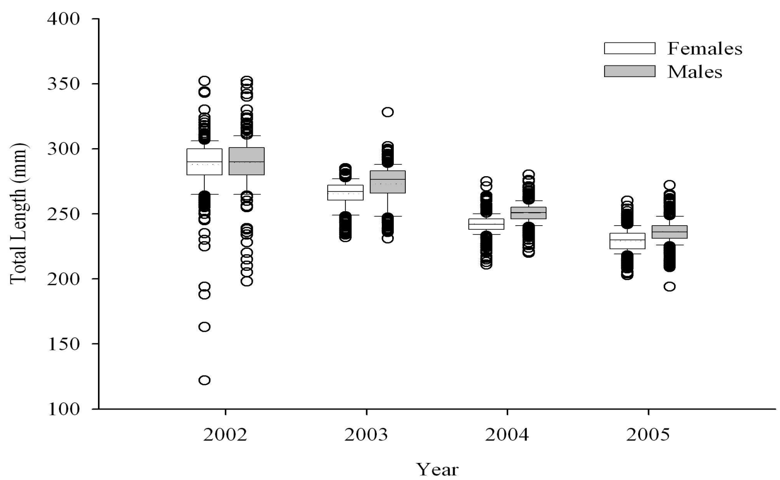

Figure 3. Plots of total length of kokanee spawning in Harvey Creek from 2002 through 2005. Boxes indicate the 25th and 75th percentiles, whiskers indicate 10th and 90th percentiles, solid lines are the median, dotted lines are the mean, and open circles are outliers. Sample sizes of females were 643 (2002), 373 (2003), 895 (2004), and 846 (2005). Sample sizes of males were 371 (2002), 491 (2003), 635 (2004), and 1,407

(2005). Lengths of each sex were significantly different between all years (Kruskal-Wallis, P <0.001; nonparametric multiple comparisons Family Error = 0.2).

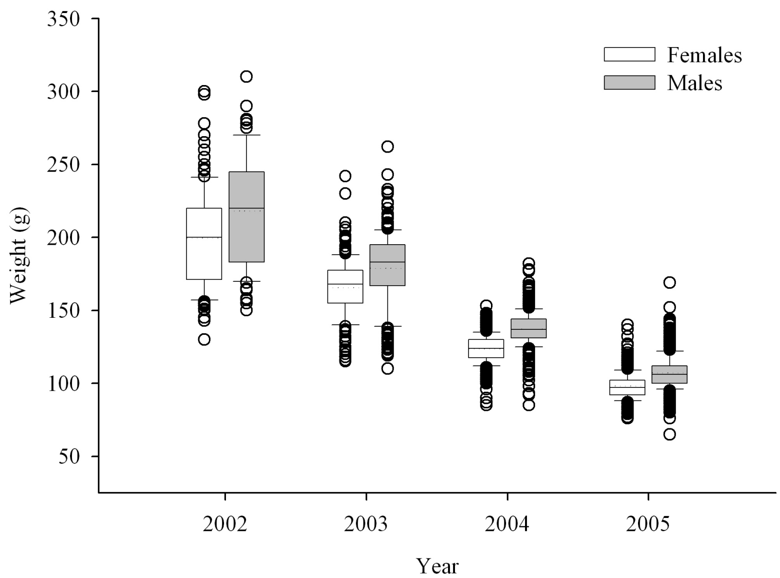

Figure 4. Plots of weight of mature and ripe kokanee spawning in Harvey Creek from 2002 through 2005. Boxes indicate the 25th and 75th percentiles, whiskers indicate 10th and 90th percentiles, solid lines are the median, dotted lines are the mean, and open

circles are outliers. Sample sizes of females were 203 (2002), 249 (2003), 761 (2004), and 502 (2005). Sample sizes of males were 127 (2002), 349 (2003), 541 (2004), and 1048 (2005). Weights of each sex were significantly different between all years (Kruskal-Wallis, $P < 0.001$; nonparametric multiple comparisons Family Error = 0.2).

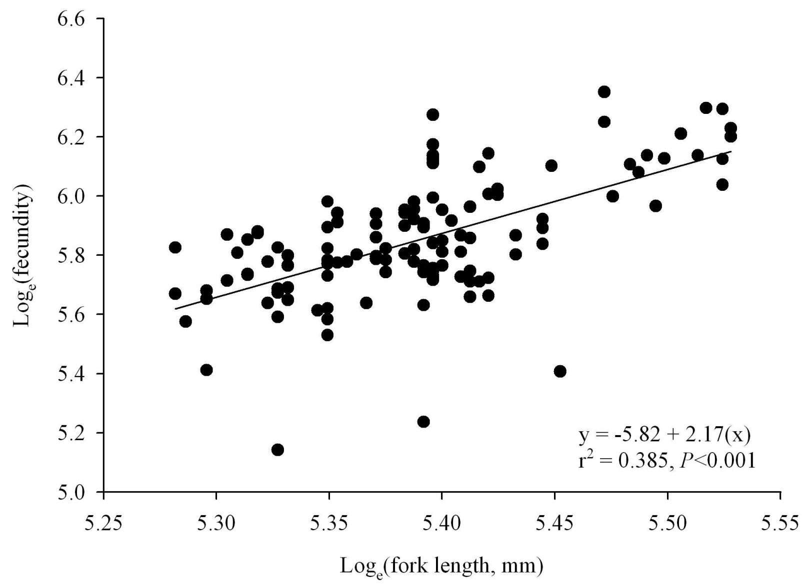

Figure 5. The Log$_e$ transformed relationship of fecundity and fork length of kokanee spawning in Harvey Creek from 2003 through 2005.